Field studies of thermal comfort in heritage hotel buildings in warm humid climate of India

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Abstract

Heritage Buildings in India roughly constitute 20% of the existing built stock. Significant energy and carbon savings is possible if these heritage buildings are put to new use. However 'Adaptive Reuse' of heritage buildings is a challenging task where energy use is strongly influenced by occupant behaviour and conservation techniques keeping in mind the historic value and traditional construction techniques of the building. This paper showcases field study findings of occupant thermal comfort for a mixed mode heritage building put to new use as a hotel - located in the warm humid climate of West Bengal, India. A total of 205 subjects were surveyed spread over four seasons. The field data was collected through yearlong monitoring of environmental parameters along with occupant surveys through spot measurements and questionnaires. This transverse survey showcases thermal preferences & thermal comfort behaviour of respondents spread over the year indicating roughly 80% of occupants are comfortable with a calculated comfort temperature of 26.7°C. The indoor climatic data was collected by instruments which complied with the accuracy standards of ASHRAE Standard-55 and ISO 7726:2001. The questionnaire was based on standard ASHRAE format for thermal environment. The study showcases the extent of thermal comfort achieved in an adapted heritage hotel along with environmental adaptive design features for suitable thermal adaptation indicating that the environmental adaptive design features alter the outdoor temperatures by an average of 1.2 °C closer to comfort temperature across the summer and winter seasons.

Keywords - Thermal Comfort, Heritage Buildings, Adaptive Reuse, Energy Efficiency, Heritage Hotels

1. Introduction

There is very little research in the field of thermal comfort for heritage buildings in India. Hence, this presents scope for investigation. This research is a pilot study for heritage hotel typology globally. Thermal comfort studies have been attempted for most building typologies like residential, commercial, museums, offices, schools, universities, but none for hotel typology. This research aims to create a starting point for scholarly discourse and further research on related topics. The study also is unique as along with thermal comfort perception, heritage perception of users is also assessed both qualitatively and quantitatively. This helps us in understanding the correlation between thermal comfort, energy efficiency and conservation of heritage buildings, which could lead to sustainable, low energy adaptive-reuse solutions.

Thermal Comfort is a basic human need. Human body has a physiological need to maintain a constant core body temperature. During thermal discomfort the body tries to regulate the heat or cold by sweating or shivering and many other such response mechanisms. One of the basic and important functions of any building is to provide shelter from external adversities. Traditional Architecture is always known to respond and adapt to its surrounding climatic conditions. The passive design features for cooling, heating or ventilation in a heritage building creates comfortable interiors as a response to its climate. India has varied climate zones which range from plains to plateaus to Himalayas to desert. The Koppen Climate classification for India is primarily Tropical Humid climate with more than 70% India falling under this classification (Am).

The varied climatic zones have led to context specific responses from traditional buildings along

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with numerous passive design features as response to the climate. Until a few decades ago most buildings responding to climate were naturally ventilated. With the penetration of air conditioning systems in our society and its easy availability, the number of conditioned buildings has grown multifold (Yash Shukla, Rajan Rawal, 2014). Most new buildings are designed to be air-conditioned. Even Heritage Buildings being put to new use are incorporating air-conditioning systems for its spaces which were historically designed to be naturally ventilated. The consequence is often high levels of energy use to over-cool buildings in summer and overheat them in winter, all too often resulting in uncomfortable if not unhealthy buildings (Mendell & Mirer, 2009).The increasing reliance on air conditioning has led to an appreciable decline in the standard of passive, environmental design skills among architects. The widespread use of air-conditioning world-wide has discouraged design of buildings that use 'passive' – non mechanical cooling strategies. The need for air-conditioning can often be significantly reduced by improving the thermal performance of the building through strategies such as reduced glazing areas, more shading, use of thermal mass, naturally ventilating the building etc. The key challenge is to design efficient buildings and use adaptive approaches to achieving comfort in them. (F. Nicol et al., n.d.).

1.1 Adaptive Thermal Comfort Model

Globally researchers have been exploring the subject of thermal comfort for more than 6-7 decades which has led to two main prevalent comfort models. The first, Fangers static heat balance model was a lab based model. This model became the basis for providing an index for thermal comfort by some international standards like ASHRAE 55, ISO 7730 initially. Since this model was developed only through controlled environment experiments and no real field data was included, many researchers were unhappy with the approach. Also it lacked research on naturally ventilated buildings. This led to a new adaptive model of thermal comfort introduced by Nicol and Humphreys in 1970's. The adaptive model was based on field survey findings and also included responses of the occupants of the buildings, keeping the researchers' perception at the minimum. The data collected was statistically analysed to arrive at results. Further extensive work in this approach was done by Brager and De dear based on which ASHRAE 55 adopted it in 2004.

Adaptive Thermal Comfort standards liberate the designer to create buildings that use natural energy from wind and sun when appropriate, to run buildings for much of the year on renewable energy and to open the windows again and restore the thermal delight that is too often absent in modern tight skinned buildings. The adaptive approach to comfort is based on the Adaptive Principle: If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort. (F. Nicol et al., n.d.)

The natural tendency of people to adapt to its changing environment is expressed in the adaptive approach to thermal comfort. The adaptive approach works with the field surveys which also take into account the thermal response of the subjects in the form of comfort vote. The aim is to find the temperature or combination of thermal variables (temperature, humidity, air velocity) which subjects consider neutral or comfortable. The comfort temperature is a result of the interaction between the subjects and the building or other environment they are occupying. (J. F. Nicol & Humphreys, 2002). The environmental variables are measured at the same time as the subjective reactions are recorded. Because the aim is to obtain a reaction to typical conditions, there is no attempt to interfere with the environmental conditions, the activity or the modes of dress, and thus the full complexity of the context is included in the responses of the participants.(F. Nicol & Roaf, n.d.)

1.2 Mixed mode buildings

A mixed mode building is one where heating or cooling is achieved through both mechanical means as well as natural ventilation. A naturally ventilated building in most cases functions as a mixed mode building. For eg. in India mechanical cooling may be used in peak summer to arrive at comfort conditions but heating may not be required during winter hence allowing the thermal properties of the building to regulate the comfort conditions along with occupant responses. The mixed mode building has become less prevalent within the modern building design typologies however traditional buildings with their passive design features and natural ventilation utilise the mixed mode of operations to their benefit.

The thermal comfort conditions of most heritage buildings change spatially as well as through time. Different spaces are used at different times of the day as per the external climate and its effect on the indoor environment. The approach to comfort in modern buildings is centred on the use of air conditioning hence assuming that constant conditions are more comfortable than variable conditions. There is a danger that building regulations will require traditional buildings to conform to this modern paradigm, ignoring the intentions of the original designer or builder. The adaptive approach has eroded the notion that unchanging conditions are superior by showing that indoor comfort can change in time according to outdoor conditions. On the basis of adaptive principle there is no reason why this cannot be extended to environments that change in space as well as in time. (F. Nicol et al., n.d.) Conservation of heritage buildings through retrofitting or restoring not only helps to preserve heritage but also provide low carbon, energy efficient solutions for reuse keeping indoor thermal comfort of occupants as their primary concern.

West Bengal state in India is known for its stunningly beautiful palaces and mansions especially Kolkata nicknamed as the 'City of Palaces'. Kolkata, the capital city of the state of West Bengal was the seat of imperial power during the 18th & 19th century. The region then known as the Bengal Presidency has been witness to great social, political, and historical turmoil during the period referred to as the 'Bengal Renaissance'. The building stock of Kolkata and its surroundings is dotted with beautiful Grand Pre and post British era palaces or zamindar baris. The intent to save these heritage buildings was projected by the government of West Bengal as a result of which the phenomenon of rehabilitating old buildings by putting them to new use became rampant. 'The state government has decided to use a cluster of 100 palatial properties across the state to convert them into heritage hotels, a trend accepted by the property owners.' (Tamaghna Banerjee & udit prasanna mukherji, 2022)

With this context, a field study was undertaken to evaluate the indoor thermal comfort achieved within Bawali Rajbari, a heritage building put to new use as a heritage hotel in West Bengal. Occupant thermal comfort analysis was also conducted in order to assess the adequacy / comfort of indoor conditions for the new occupancy pattern.

This paper intends to showcase the thermal comfort solutions by analysing the data gathered in the field study of the heritage hotel in West Bengal. The study showcases the extent of thermal comfort achieved in an adapted heritage hotel along with environmental adaptive design features for suitable thermal adaptation.

2. Methods

2.1 The Rajbari Adaptive Reuse as a Heritage Hotel

The 'Rajbari' is a traditional building typology in West Bengal. These large palatial houses of the British era are representative of traditional residential architecture of West Bengal and contribute to the large spectrum of heritage buildings in the state. There is a prevailing trend of conversions of these heritage houses into 'Heritage Hotels' within the state. This traditional building typology demonstrates many passive design strategies highlighting historic comfort parameters worthy of evaluation. Originally designed as a naturally ventilated building, it is today a mixed mode building (naturally & mechanically ventilated) post its adaptive reuse and presents a case to demonstrate adaptive thermal comfort concept. Bawali Rajbari is located in the town of Budge-Budge, South 24 Parganas district of West Bengal. The Rajbari was owned by the Mondal dynasty in the late 18th century. The Rajbari, an architectural masterpiece, was built 250 years ago. It saw approximately 150 years of continuous occupation till the family lost most of its wealth, and the palatial house fell into disrepair. It was only in 2017 that the Rajbari, was rediscovered, restored and adapted as a heritage hotel to reflect the opulence of the Zamindars of Bengal. The Rajbari today sits on a 3 acre land with ponds and gardens adding to the surrounding.

2.2 The adaptive mechanisms for thermal comfort

The concept of adaptive reuse was executed in a manner to restore maximum authentic existing historic parts of the building. As far as possible original building materials were retained, and new additions were made with compatible materials sourced locally. This traditional naturally ventilated typology displays the following prominent architectural characteristics showcasing its passive design features and climate responsiveness.

- Central courtyard to avoid heat gains and allows the courtyard to act as an air sink to ventilate the surroundings.
- Strategic positioning of large doors & windows, to help achieve comfort ventilation.
- Thermally massive construction to moderate temperature swings.
- Deep verandahs / arcaded corridors on ground and first floor around the central courtyard act as a buffer space to provide filtered daylight, solar shading and ventilation.
- Use of wooden slats between the corridor columns act as a screen to prevent heat gain.
- Proximity to the water body and surrounding greens adds to the micro climatic effect and cools the surroundings.

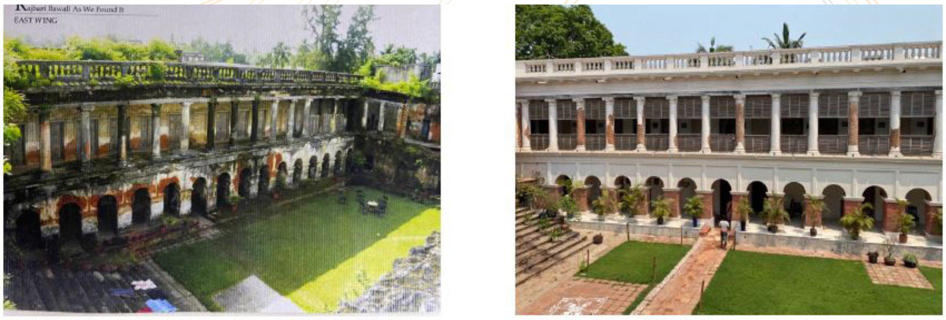


Figure 1 and 2: East wing – Before & after Restoration 2.3

Field Survey

Transverse field surveys were conducted for the heritage hotel from April 2021 to May 2022. The surveys were spread over a year and gathered environmental variables as well as occupant comfort response data. The environmental variables of air temperature (ta) and relative humidity (RH) was collected with the help of loggers/ sensors through a continuous yearlong data logging. This was supplemented by the spot measurements of the environmental variables (Ta, Tg, RH, Va) taken every quarter (April, October, January, May) during the four seasons, along with the data for comfort vote which was collected through the process of Right Now Right Here (RNRH) survey.

Figure 3,4 and 5: Pictures during thermal comfort survey

2.4 Sampling Stratification & Questionnaires

The survey involved a total of 205 subjects divided over the four seasons of summer, rainy, winter and autumn. Each quarter the survey was conducted over 7/10 days within the chosen month. Nearly 96% of the subjects surveyed belonged to West Bengal and had been living in the state for more than 15 years. It can thus be assumed that they are naturally acclimatised to the climatic conditions of West Bengal. Equal gender and age distribution of the subjects was kept in mind while surveying (Table 1).

Table 1: Distribution of samples by gender and by spatial disposition

	Male	Female	Total		Guestrooms	Public Areas	Total
Mar – Apr 21	24	26	50	Mar – Apr 21	27	23	50
Sep – Oct 21	32	28	60	Sep – Oct 21	36	24	60
Dec – Jan 22	25	30	55	Dec – Jan 22	36	19	55
Apr – May 22	22	18	40	Apr – May 22	22	18	40
Total	103	102	205	Total	121	84	205

The questionnaire was designed borrowing from the ASHRAE format but tweaking it to include heritage perception questions to understand the relationship between heritage perception and thermal perception within the heritage hotel. Besides the basic information the respondents were asked to inform about their educational background, duration of stay, how often they stayed in a heritage hotel, place of belonging, most comfortable part of the hotel and most comfortable time of the day.

2.5 Instrumentation

The following instruments were selected and used for the survey. Table 2 showcases the comparison between range and accuracy of each instrument against the ISO 7726:2001 standard. The data loggers were set to record the measurements at every 30-minute interval.

Table 2: Equipment details against ISO 7726:2001 standards

	Parameter	Range		Accuracy	
		Instrument	Standard	Instrument	Standard
Extech HT30	Globe temperature	0 - 80° C	10 - 40° C	± 2° C	± 2° C
TSI 9545-A	Air Velocity Air temperature RH	0 – 30 m/s -10° - 60° 0 - 90%	0.05 -1m/s 10 - 40° C -	± 0.015 m/s ± 0.3°C ± 3%	± 0.05 m/s ± 0.5° C -
HOBO	Air temperature RH	20° to 70° C 5% to 95% RH	10 - 40° C -	± 0.35°C ± 2.5%	± 0.5° C -
HTC EasyLog	Air temperature RH	40° to 70° C 0% to 100% RH	10 - 40° C -	± 1.0°C ± 3.0 %	± 0.5° C -

2.6 Spaces and Logger Placement

The Rajbari comprises several public and private spaces. For the monitoring and continuous data logging of environmental parameters, private spaces (Guest Rooms) and public spaces (Restaurants, Restaurant Lobby, Bar, Library Lounge & Corridors) were selected. 13 data loggers were placed within various spaces of the hotel (Fig 6&7) guest rooms (5 nos.), corridors (4 nos.) and public spaces (4 nos.). Three types of Guest Room classification were found within the hotel and the rooms were air conditioned and had ceiling fans. The hotel guests had access and control of AC thermostat, ceiling fan regulators, window blinds and door-window operations for modulating thermal comfort within the rooms. The Public spaces were found to be of three types. The restaurant and restaurant lobby were air-conditioned with no ceiling fans and openable windows. The guests did not have access to the AC controls. The Library Lounge and the Bar were air conditioned with provisions to use ceiling fans and operable windows. The corridors were naturally ventilated on both ground and first floor

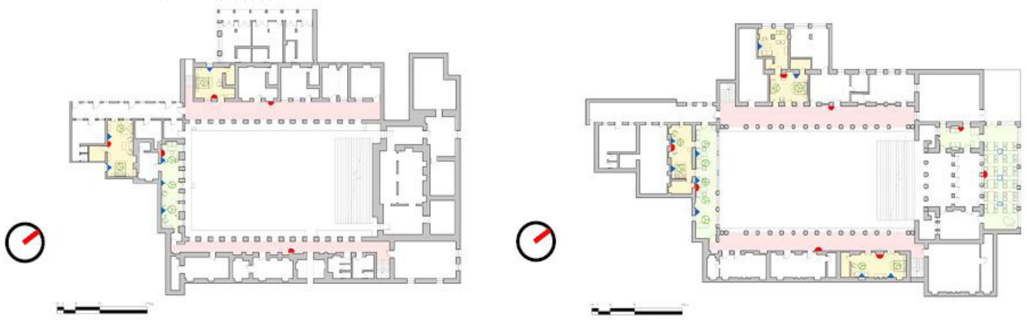


Figure 6 and 7: Ground and First floor Plan

3. Results

3.1 Building thermal data

The summary of the data gathered during a field investigation carried out at a historical hotel in West Bengal are presented in Table 3, which provides an overview of the mean maximum, standard deviation, and minimum values for air temperature and relative humidity in all sections of the hotel premises.

Table 3: Summary of indoor environment from logging sensor measurements

Spaces	n		T_a (°C)	RH (%)
Public	77586	Max	39.3	94.1
		Mean	25.5	75.9
		Std Dev	2.8	9.4
		Min	18.6	34.4
Private	96985	Max	32.1	97.1
		Mean	24.8	78.4
		Std Dev	2.5	10.8
		Min	19.0	38.4
Corridor	65510	Max	37.1	95.9
		Mean	27.2	76.9
		Std Dev	3.3	10.9
		Min	17.6	25.2

Upon analysing the average air temperature of the building on a monthly basis, it becomes evident that the coldest months are January, February, and December. Conversely, the hottest months are March, April, May, and June, with June being the warmest among them. The transitional months, which align with the rainy season, are March, July, August, September, and October. When examining the diurnal variation throughout the day, it is observed that there is no significant fluctuation in temperature for the entire building on average (Figure 8). However, the warmest period occurs between approximately midday and approximately 16:00 in the afternoon. The diurnal variation is more pronounced when the average temperature is assessed on a room-by-room basis, rather than considering the temperature of the entire structure as a whole (Figure 8).

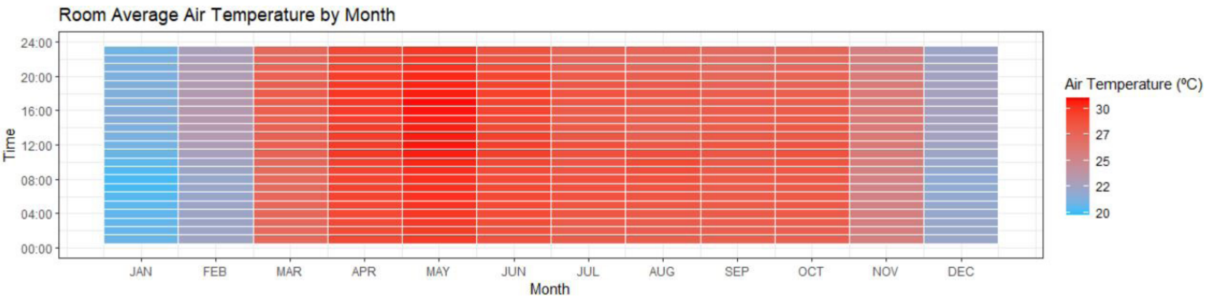


Figure 8: The presented plot illustrates the average daily air temperature (Ta) and relative humidity (RH) each month across the entire building. The data was acquired through placed sensors, with warmer air temperatures represented by the colour red and colder air temperatures represented by the colour blue.

Analysing the monthly average relative humidity within the building, it becomes evident that there is a notable increase in humidity levels during the summer season. The time period characterized by the lowest average relative humidity, typically hovering around 50%, occurs primarily throughout the months of March and April, specifically between noon and approximately 16:00. During the period from June to October, particularly in the morning hours. During the hours spanning from approximately 07:00 to 11:00, there is a notable increase in relative humidity, reaching an average of almost 90%, which coincides with the occurrence of the rainy season (Figure 8).

This study determines the building's warmest and coolest average day by measuring air temperature and relative humidity. A thorough analysis is needed to show how an adapted heritage hotel can achieve thermal comfort. Daily air temperature data shows a 20-24 °C variation in the average temperature during January, February, and December.
January 29th has the lowest average temperature. From April to early July, the average temperature fluctuates between 25 °C to 30 °C, with the highest recorded temperature on May 24th (Figure 9). However, relative humidity remains high year-round, with a lower average during warmer months and a higher average during rainier months.

Figure 9: The Illustration depicts the average daily air temperature (Ta) (top) and relative humidity (RH) (bottom) for the entire building over the course of a year.

The highest summer temperature in the building is between 14:00 and 16:00. During this instance, the peak temperature reached around 28 °C. Note that relative humidity peaks at 15:00 on the hottest summer day, around 78% (Figure). On the typical rainy season day, the building's air temperature rises in the morning and falls in the evening. However, daytime temperature variation is usually one or two degrees, indicating a stable pattern. The average daily variation in relative humidity is 10%. In particular, relative humidity is higher in the morning and decreases in the evening. On the coldest winter day, air temperature and relative humidity are parallel and different from other seasons. The air temperature gradually rises after sunrise, peaking at around 14:00 at 21 °C. The temperature gradually decreases until night-time, averaging around 20 °C. On a typical cold winter day, relative humidity drops by 7% as the temperature rises. This decrease in relative humidity occurs from night and early morning to noon and afternoon.

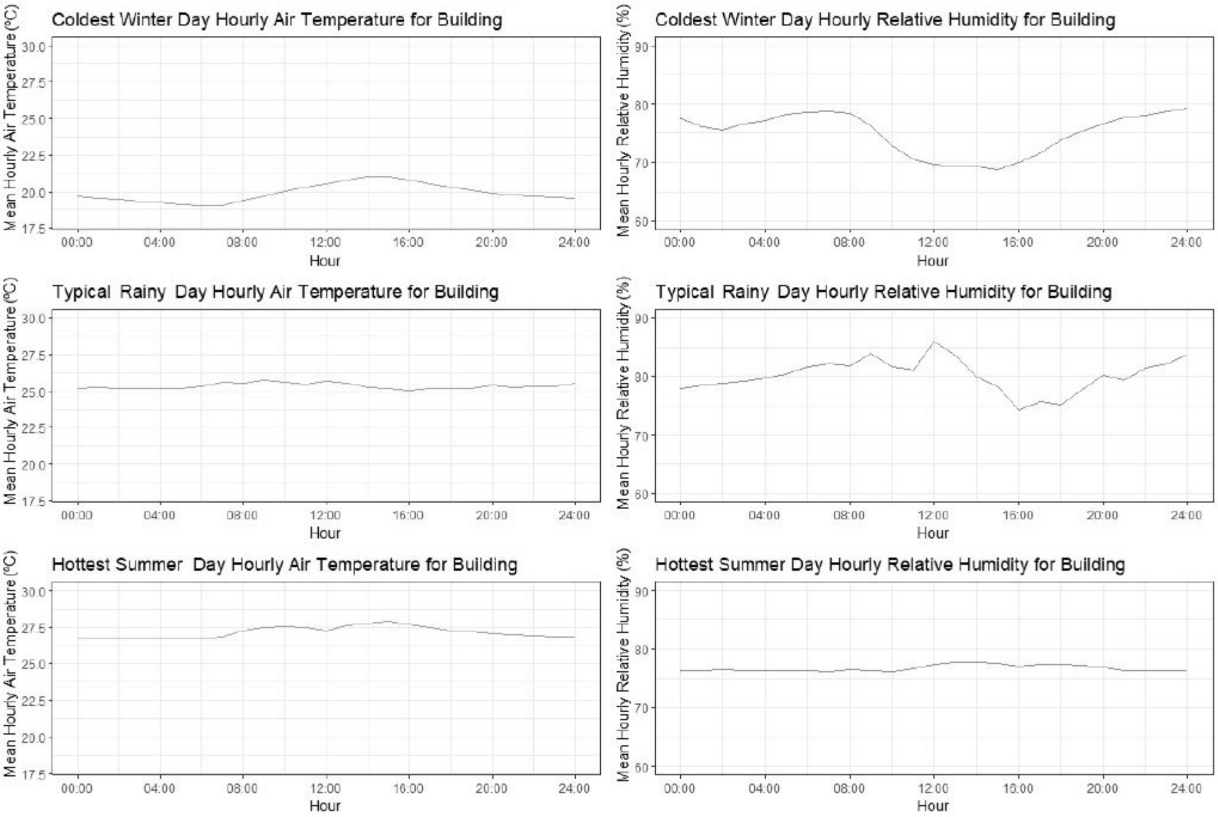


Figure 10: The illustration describes the average hourly air temperature (Ta) represented on the left, and the relative humidity (RH) represented on the right, across the entire building. This data corresponds to the average coldest temperature seen throughout the winter season, on January 29, the average typical temperature seen throughout the rainy season, on October 18, and the average hottest temperature seen throughout the summer season, on May 24, as gathered during the designated data period.

3.2 Building occupant data.

In all four seasons, 205 participants were interviewed for spot measurements (Table 4). In public spaces, females had an average air temperature of 25.5°C, with a standard deviation of 3.3°. In contrast, males had an average air temperature of 25.7°C and a standard deviation of 1.6°. The average RH for females was 75.8% and for males 76.1%. These values had a 9.8% standard deviation. Mean radiant temperature (Tr) depends on globe temperature (Tg). The operational temperature (To) was calculated by adding the ambient temperature (Ta) and the (Tr). The study found operational temperature differences by gender and space. Females experienced temperatures ranging from 25.6 °C in public spaces to 26.0 °C in private spaces. The temperature ranged from 25.3°C in public spaces to 25.6°C in private spaces for males. The mean radiant temperature (Tr) varied slightly by gender and space. Public spaces had an average Tr of 25.6 °C, while female private spaces had a slightly higher average Tr of 26.7 °C. In contrast, males had an average Tr of 24.9 °C in public and 25.6 °C in private spaces.

Table 4: Summary of indoor environment from spot measurements and occupant thermal perception classified under public & private spaces with gender-based responses.

Spaces		n		T_a (°C)	T_r (°C)	To (°C)	RH (%)	V_a (m/s)	clo	met	TSV	TPV
Public Spaces	Female	45	Mean	25.5	25.6	25.6	76	0.2	0.9	1.6	-0.78	1.78
			Std Dev	3.3	2.6	3.0	10	0.2	0.3	0.5	0.79	0.67
	Male	45	Mean	25.7	24.9	25.3	76	0.2	1.0	1.4	-0.71	1.51
			Std Dev	1.6	2.4	2.0	10	0.1	0.3	0.6	0.63	0.82
Private Spaces	Female	57	Mean	25.2	26.7	26.0	77	0.2	1.1	1.5	-0.68	1.72
			Std Dev	3.0	3.7	3.4	8	0.2	0.1	0.5	0.91	0.92
	Male	58	Mean	25.5	25.6	25.6	76	0.2	0.9	1.6	-0.71	1.64
			Std Dev	3.3	2.6	3.0	10	0.2	0.3	0.5	0.99	0.81

The average thermal insulation value of clothing (clo) exhibited a range of 0.9 clo to 1.1 clo for females in public settings, while for females in private settings it remained at 1.0 clo. In the case of males, the thermal insulation value was 1.0 clo in public settings and decreased to 0.9 clo in private settings. The metabolic rates exhibited a range of 1.6 to 1.5 metabolic equivalents (met) for females in both public and private settings, whereas for males, the range was 1.4 met in public settings to 1.6 met in private settings. In both public and private spaces, the air velocity (Va) remains below 0.2 m/s for both male and female individuals.

3.2.1 Annual occupant thermal comfort.

The present study examines the thermal sensation vote (TSV) and thermal preference vote (TPV) data collected from a sample of 205 occupants in order to gain insights into the level of thermal comfort achieved in an adapted heritage hotel. The thermal sensation vote (TSV) and the thermal preference vote (TPV) are commonly used metrics in thermal comfort research. The Thermal Sensation Vote (TSV) is a quantitative measure that assesses the thermal perception of individuals by collecting their subjective responses on a seven-point thermal scale. This scale ranges from a rating of "cold" (-3) to "neutral" (0) and finally to "hot" (+3). The Thermal Preference Vote (TPV) is a measure used to determine an occupant's preference for either a warmer or colder thermal environment. It is assessed using a preference scale consisting of 5 points. Each point on the scale represents a vote for a warmer temperature, no change in temperature, or a cooler temperature. Additionally, this analysis sheds light on the environmental adaptive design features that facilitate appropriate thermal adaptation in the hotel. Regarding the TSV (thermal sensation vote), it is apparent that a significant proportion of the individuals surveyed report a rating of -1, signifying a subtle perception of coolness. In relation to TPV, it is evident that the majority of votes primarily lie within the interval of -1 to +1. This finding indicates that a notable proportion of the individuals occupying the building exhibit a preference for maintaining the existing thermal conditions without making any modifications (Figure 11).

The TPV is utilized to assess an occupant's inclination towards a warmer or cooler thermal environment, as quantified on a preference scale. This scale employs terms such as "cooler," and "warmer" to, while "no change" acts as the neutral position. The range of votes, span from -1 to +1, suggests a significant level of applicability for the current temperature conditions observed across this study. This observation aligns with several studies that utilize thermal preference voting (TPV)

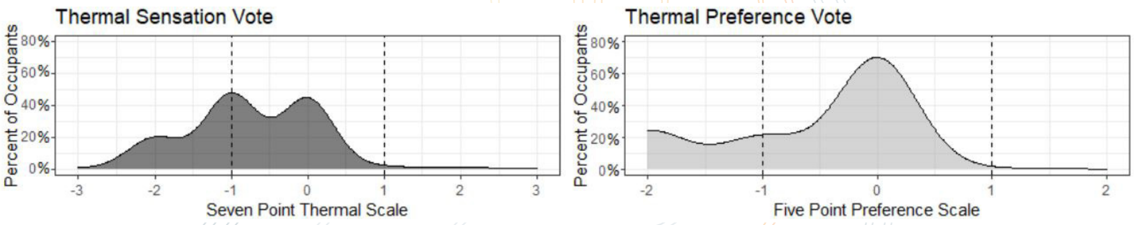


Figure 11: A density plot illustrating the comparison between the thermal sensation vote and the thermal preference vote throughout the entirety of the study period for all 205 occupants surveyed as a total.

as a means to assess occupant preferences. (Indraganti & Boussaa, 2017) (Damiati et al., n.d.) (Aghniaey et al., n.d.) In addition, the thermal acceptance among the sampled population exhibited an average value of 96%.

3.2.2 Seasonal occupant thermal comfort.

The study of thermal comfort on a seasonal basis involved the examination of 205 data points collected from occupants, specifically during the winter, rainy, and summer seasons. The present analysis primarily examined three thermal comfort metrics, specifically the Thermal Sensation Vote (TSV) and the Thermal Preference Vote (TPV) (see Figure 12).

In the context of TSV, it has been noted that there is a moderate decline in voting frequency during both winter and summer seasons, showing a peak in voting activity during slightly cooler periods (-1). However, in the period of increased precipitation, TSV also indicates that individuals may experience a slight sensation of coolness, with a decrease of approximately one degree. Furthermore, it has been observed that there is a rise in the number of individuals who choose to remain neutral (0) during the rainy season (see Figure).

A similar pattern can be observed in the case of TPV, where the most significant level of voting activity occurs during periods of rainfall, with the peak falling between the ranges of -1 to +1. Following this, the distribution gradually ranges from -2 to 0 in both winter and summer seasons with individuals generally preferring to maintain the existing thermal conditions, as evidenced by a majority voting for no alteration (0) (Figure 12).

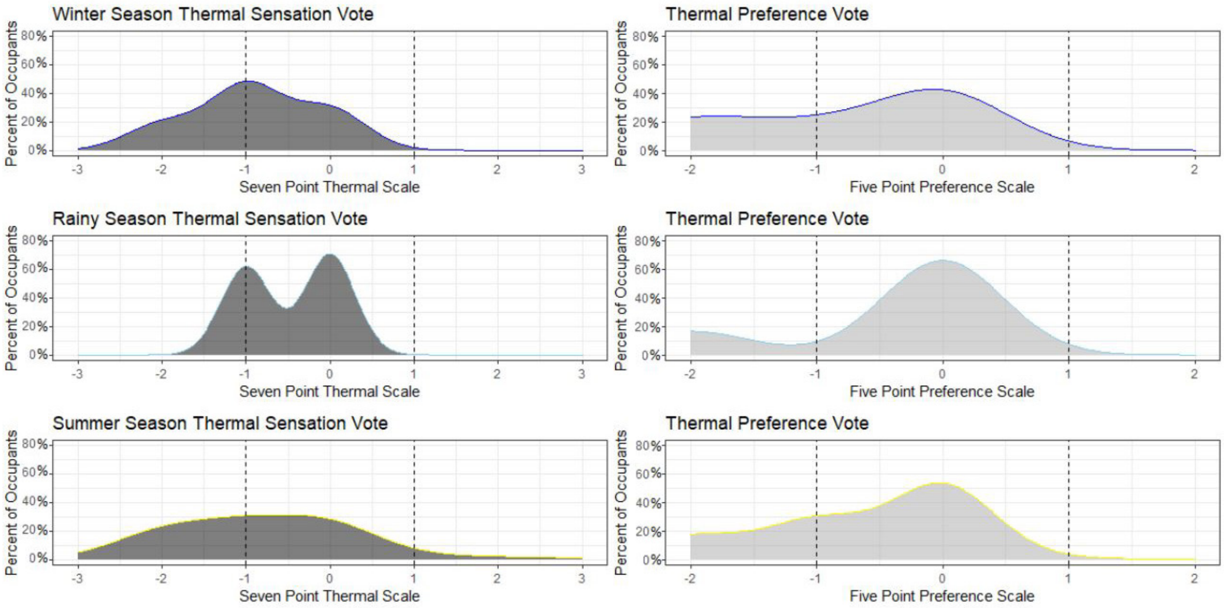


Figure 12: A density plot illustrating the thermal sensation vote (TSV) and the thermal preference vote (TPV) throughout the entirety of the study period for all 205 occupants surveyed across the winter, rainy, and summer seasons.

3.3 Assessment of thermal comfort and the comfort temperature.

To assess the optimal temperature for maximising occupant comfort within a building, the thermal sensation votes (TSV) are analysed in relation to the operative temperature. A regression analysis is conducted to examine the relationship between the thermal sensation vote and the operative temperature, utilising the dataset consisting of a total of 205 votes. The TSV voting results indicate a prevailing trend towards neutrality, as around 40% of the votes are assigned a value of 0 and approximately 80% of the votes fall within the range of -1 to +1. Furthermore, the TSV is recorded on discrete values spanning from -3 to +3. This limitation has a detrimental effect on the precision of the regression analysis conducted for the neutral temperature. This is evident from the R-squared value, which is less than 1% (Figure 13).

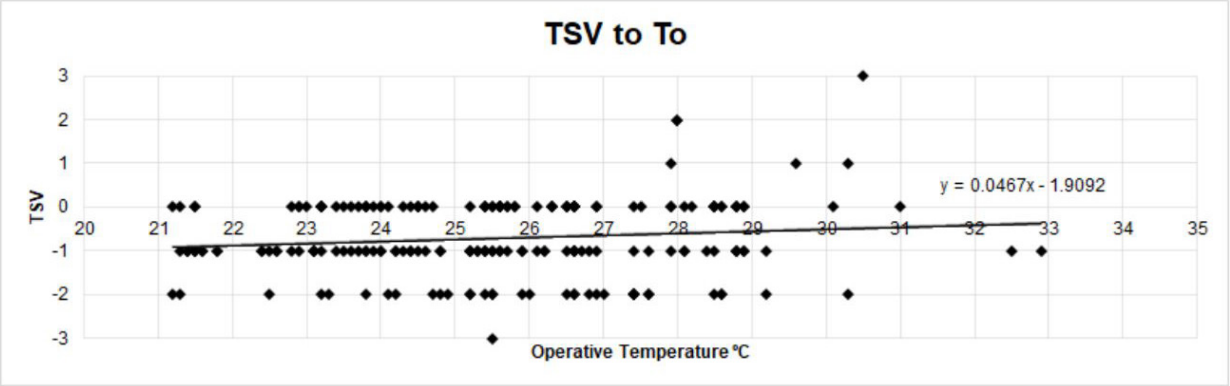


Figure 13: The figure depicts a regression analysis conducted on the relationship between the collected TSV (thermal sensation vote) and the operative temperature for the entire study population consisting of 205 occupants.

In the context of regression analysis, the term "neutral temperature" pertains to the values of the slope and intercept when the seven-point thermal scale is set to zero. These values are indicative of a neutral occupant sensation. The regression analysis conducted for the TSV revealed an observed Tn value of 40.9 °C, which is considered implausible. As the observed Tn surpasses 40 °C, it suggests a diminished level of confidence in the TSV regression model. Nevertheless, the TSV regression model possesses inherent limitations. A low slope with the regression indicates that the occupants have a reduced thermal sensitivity in relation to a specific temperature.

This finding demonstrates that the accuracy of estimating the comfort temperature may be questionable when the regression coefficient is low as evident in similar thermal comfort research. (Aqilah et al., n.d.) (Lamsal et al., n.d.) Hence, the Griffiths method emerges as the most appropriate approach for determining the comfort temperature as frequently deployed in thermal comfort studies in similar regions. (Humphreys & Nicol, n.d.) (Griffiths, 1991) (Humphreys et al., 2013) (Indraganti, 2010b) (Indraganti, 2010a) (F. Nicol & Roaf, n.d.-a) (Alnuaimi et al., 2022).

The Griffiths method is utilized using equation: Tc=Tr+ (0−TSV)/G

The determination of the comfort temperature (Tc) was conducted utilising the Griffiths method, encompassing the entire sample size of 205 individuals who participated in the study. The Griffiths method, in a broad sense, correlates the indoor temperature with the individual inclinations of occupants regarding the TSV in order to determine a specific comfort temperature for each individual. Subsequently, the mean comfort temperature of the population is determined by calculating the average comfort temperature for all individuals included in the study. In thermal comfort studies, it is conventional for the Griffiths method to employ a G constant of 0.50, 0.33, and 0.25 which corresponds to a variation of either 2°C, 3°C, or 4°C in indoor temperature, resulting in a shift of thermal sensation by one unit on the 7-point scale, respectfully. Table 5 presents the Tc corresponding to the respective values, and it illustrates an average temperature variation of 1 °C across the range of G values considered. This finding indicates that the average Tc, as determined by the Griffiths method, is approximately 26.7 °C. The estimation of the comfort temperature presented in this study is considered the most plausible due to its alignment with the voting pattern of the occupants surveyed, as indicated by the TSV and TPV.

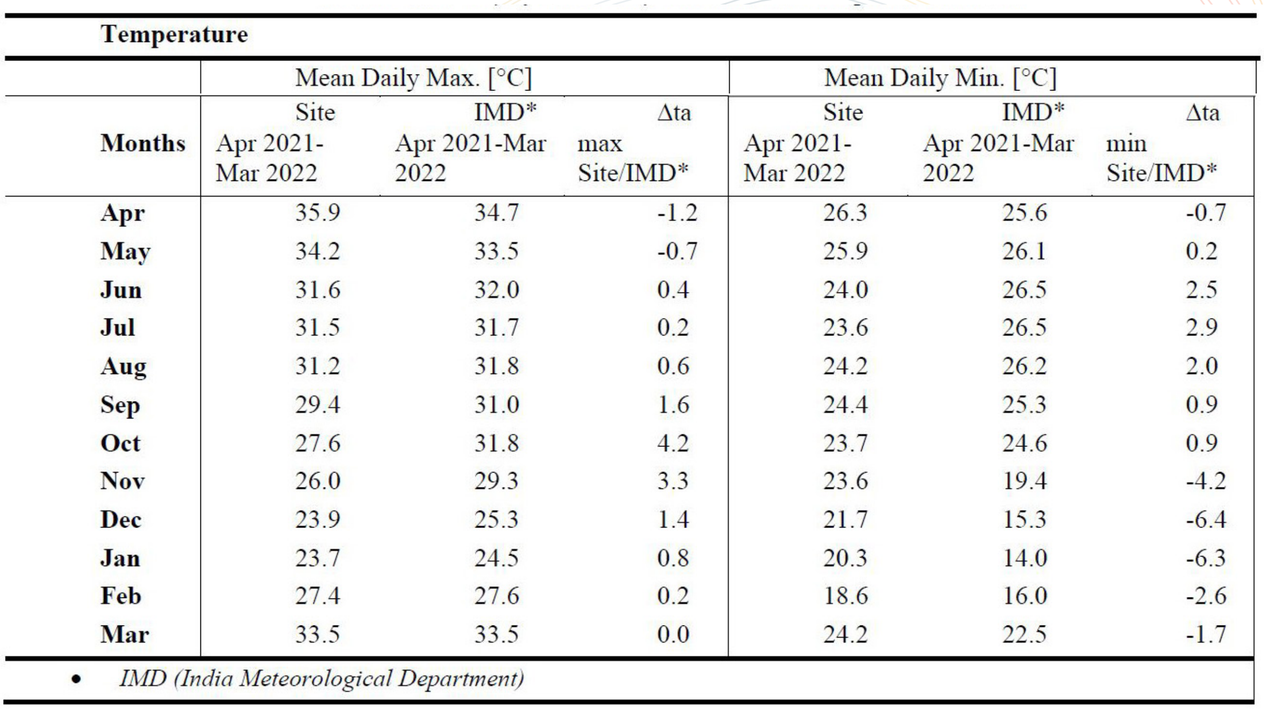
Table 5: Summary of comfort temperature calculated through Griffiths method.

G Constant	**0.5/°C**	**0.33/°C**	**0.25/°C**
Comfort Temperature	26.2 °C	26.7 °C	27.2 °C

3.4 The effect of the environmental adaptive design features in achieving thermal comfort.

In order to ascertain the extent to which passive systems in the building contribute to thermal comfort, it is necessary to compare the temperatures observed during a given month in the absence of the building (IMD (India Meteorological Department) Temperature) with the temperatures recorded in the unconditioned spaces within the building (Site Temperature) (Table 6). The spaces which depict the site temperature are the four corridors, which are situated on the first floor and ground floor in the eastern and western directions. These corridors are unconditioned, meaning they lack active climate control systems. When conducting a comparison between the two, it becomes evident that during the summer season, the unconditioned spaces of the building tend to exhibit lower temperatures, while in the winter season, they tend to be warmer (Figure 14). The mean site temperature throughout the year is observed to be more closely aligned with the calculated comfort temperature, in comparison to the offsite temperature.

Table 6: Summary of mean daily max. and min. temperature on site.



Temperature

	Mean Daily Max. [°C]			Mean Daily Min. [°C]		
Months	Site Apr 2021-Mar 2022	IMD* Apr 2021-Mar 2022	Δta max Site/IMD*	Site Apr 2021-Mar 2022	IMD* Apr 2021-Mar 2022	Δta min Site/IMD*
Apr	35.9	34.7	-1.2	26.3	25.6	-0.7
May	34.2	33.5	-0.7	25.9	26.1	0.2
Jun	31.6	32.0	0.4	24.0	26.5	2.5
Jul	31.5	31.7	0.2	23.6	26.5	2.9
Aug	31.2	31.8	0.6	24.2	26.2	2.0
Sep	29.4	31.0	1.6	24.4	25.3	0.9
Oct	27.6	31.8	4.2	23.7	24.6	0.9
Nov	26.0	29.3	3.3	23.6	19.4	-4.2
Dec	23.9	25.3	1.4	21.7	15.3	-6.4
Jan	23.7	24.5	0.8	20.3	14.0	-6.3
Feb	27.4	27.6	0.2	18.6	16.0	-2.6
Mar	33.5	33.5	0.0	24.2	22.5	-1.7

- *IMD (India Meteorological Department)*

The seasons examined correspond to the distinct seasons of summer, winter, and rainy seasons as observed in Figure 9. The observed temperature difference between the Indian Meteorological Department (IMD) and the local site temperature exhibits a mean deviation of approximately 0.2 °C cooler during the summer season, 1.1 °C during the rainy season, and 2.1 °C warmer in winter (Fig. 14). This implies that the implementation of thermal comfort solutions at the heritage hotel in West Bengal contributes to the attainment of thermal comfort in a greater capacity as opposed to site conditions alone.

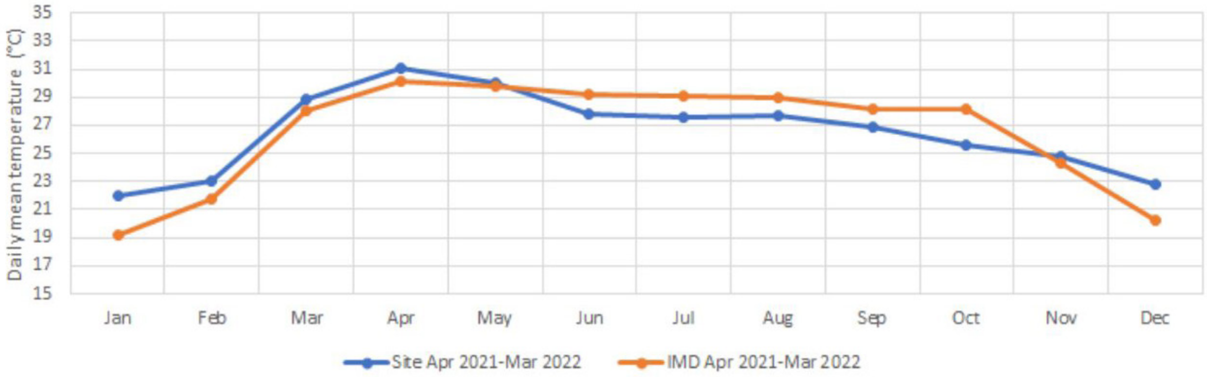


Figure 14: The provided figure represents a plot illustrating the IMD temperature data for the daily mean temperature of each month, in comparison to the daily mean temperature by month recorded from the building site using data loggers that are located in the unconditioned spaces throughout the corridors of the building,

4. Discussion

The data shows three distinct seasons. The winter season runs from December to February. The second season, summer, runs from March to June. Finally, the third season, from July to November, is the typical rainy season due to its similar Ta and RH patterns. 205 occupants were examined, occupant thermal acceptability averaged 96%, suggesting a slight preference for cooler thermal sensations. Winter was slightly cooler and occupants wanted more warmth than summer. This implies that summer passive strategies work better than winter ones. Rainy season had a moderate impact on indoor climate. The building's calculated comfort temperature was 26.7°C using the Griffiths method. Comparing this with other studies conducted in India (Indraganti, 2010a), (Indraganti et al., 2013) the comfort band based on the regression analysis was found to be 26–32.45 °C with the neutral temperature at 29.23 °C. We had 26.7°C which is similar to what researchers have found in similar climates in India.

. The building's passive strategies reduce summertime external conditions, bringing indoor spaces closer to the desired temperature. This shows that the building's passive strategies maintain thermal comfort.

The preliminary results lead to the need for proposing appropriate design solutions towards environmental & thermal adaptations within heritage buildings being put to new use. The study reveals there are comfort standards for new buildings but none for heritage buildings. Mixed mode buildings is increasingly becoming a norm in India especially of 12 with heritage buildings where passive design features exist and can be suitable and adapted to new use. The indoor environment for such buildings can be designed to encourage the use of existing passive design features and reduce dependency on conventional air conditioning techniques. The PMV and TSV analysis shows that people are willing to compromise on thermal comfort for heritage experience.

Evidenced with other energy efficiency and thermal comfort studies done on historic buildings (Sakkaf-Al et al., 2021), (Molina Martinez et al., 2016), the increase in the importance of energy efficiency and thermal comfort as in most parts of the world can also be felt in India demonstrated through the research conducted. It is seen that the user's tolerance level is high while experiencing heritage buildings.

5. Conclusion

The following main points emerge in the paper:

- This paper presents the findings of a field study conducted to assess the thermal comfort of a Heritage Hotel building in a warm and humid climate in India. From the 205 occupant votes, the TSV voting data illustrate an indication of thermal sensation over the year toward neutrality, with 40% of votes being 0 and 80% being -1 to +1 and with TPV majority voting for no change.
- This study aims to demonstrate the efficacy of thermal comfort solutions through the analysis of data collected during a field study conducted at a heritage hotel in West Bengal. Additionally, this study highlights the degree of thermal comfort attained in a modified heritage hotel, as well as the environmental adaptive design elements implemented to facilitate appropriate thermal adaptation.
- Using the Griffiths method, a comfort temperature of roughly 26.7°C is observed. In addition, a comparison between the hotel external temperatures and the local weather station temperature during the span of the study illustrate that the implementation of thermal comfort solutions at the heritage hotel in West Bengal contributes to the attainment of thermal comfort in a greater capacity as opposed to site conditions alone.
- The average winter external temperatures of the hotel are 1.6°C warmer than the local weather station temperature of 22.7°C and in the summer, they are 0.9°C cooler compared to the local weather station average of 29.4°C, which is an average of 1.2°C across summer and winter. This

study examines the mixed mode operations of a heritage hotel building, with a particular focus on minimising the use of mechanical systems throughout the year.

- The study emphasises the importance of enhancing and reusing prevalent passive design features to achieve optimal thermal comfort within the heritage building. This observation suggests that the adaptive approach is a viable strategy for attaining comfort.

6. References

Aghniaey, S., Lawrence, M. T., Sharpton Nicole, T., & Douglass Paul, S. (n.d.). Thermal comfort evaluation in campus classrooms during room temperature adjustment corresponding to demand response. https://doi.org/doi:10.1016/j.buildenv.2018.11

Alnuaimi, A., Natarajan, S., & Kershaw, T. (2022). The comfort and energy impact of overcooled buildings in warm
climates. Energy and Buildings, 260, 111938. https://doi.org/10.1016/j.enbuild.2022.111938

Aqilah, N., Rijal, H. B., & Zaki, S. A. (n.d.). A Review of Thermal Comfort in Residential Buildings: Comfort Threads and Energy Saving Potential. https://doi.org/▪ https://doi.org/10.3390/en15239012

Damiati, S., Zaki, S. A., Wonorahardjo, S., Ali Mat, M., & Rijal, H. B. (n.d.). Thermal Comfort Survey in Office Buildings in Bandung, Indonesia.

Griffiths, I. D. (1991). Thermal comfort in buildings with passive solar features: Field studies (p. 35). Commission of the European Union.

Humphreys, M. A., & Nicol, J. F. (n.d.). Outdoor Temperature and Indoor Thermal Comfort: Raising the Precision of the Relationship for the 1998 ASHRAE Database of Field Studies. Ashrae Trans. 2000, 106(2):485-92.

Humphreys, M. A., Rijal, H. B., & Nicol, J. F. (2013). Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. Building and Environment, 63:40-55. https://doi.org/10.1016/j.buildenv.2013.01.024

Indraganti, M. (2010a). Using the adaptive model of thermal comfort for obtaining indoor neutral temperature: Findings from a field study in Hyderabad, India. Building and Environment, 45(3):519-36.

Indraganti, M. (2010b). Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India. Building and Environment, 87(3):866-83.

Indraganti, M., & Boussaa, D. (2017). Comfort temperature and occupant adaptive behavior in offices in Qatar during summer. Energy and Buildings, 150, 23–36. https://doi.org/10.1016/j.enbuild.2017.05.063

Indraganti, M., Ooka, R., & Rijal, H. B. (2013). Field investigation of comfort temperature in Indian office buildings: A case of Chennai and Hyderabad. Building and Environment, 65, 195–214.
https://doi.org/10.1016/j.buildenv.2013.04.007

Lamsal, P., Bajracharya, S. B., & Rijal, H. B. (n.d.). A Review on Adaptive Thermal Comfort of Office Building for Energy-Saving Building Design. https://doi.org/10.3390/en16031524

Mendell, M. J., & Mirer, A. G. (2009). Indoor thermal factors and symptoms in office workers: Findings from the US EPA BASE study. Indoor Air, 19(4), 291–302. https://doi.org/10.1111/j.1600-0668.2009.00592.x

Molina Martinez, A., Ausina Tort, I., Cho, S., & Vivancos Luis, J. (2016). Energy efficiency and thermal comfort in historic buildings: A review. Renewable and Sustainable Energy Reviews, 61.

Nicol, F., Humphreys, M., & Roaf, S. (n.d.). Adaptive Thermal Comfort: Principles and Practice. 5.
Nicol, F., & Roaf, S. (n.d.-a). Pioneering new indoor temperature standards: The Pakistan project. Energy and Buildings, 1996, 23(3):169-74. https://doi.org/10.1016/0378-7788(95)00941-8

Nicol, F., & Roaf, S. (n.d.-b). Progress on Passive Cooling: Adaptive Thermal Comfort and Passive Architecture. 30.

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings, 34(6), 563–572. https://doi.org/10.1016/S0378-7788(02)00006-3

Sakkaf-Al, A., Abdelkader M, E., Mahmoud, S., & Bagchi, A. (2021). Studying Energy Performance and Thermal Comfort Conditions in Heritage Buildings: A Case Study of Murabba Palace. Sustainability, 13(21), 12250. https://doi.org/10.3390/su132112250

Tamaghna Banerjee & udit prasanna mukherji. (2022, May 17). Promoting rajbaris will boost tourism in bengal. Times of India Newspaper. https://timesofindia.indiatimes.com/city/kolkata/promoting-rajbaris-will-boost-tourism-inbengal/articleshow/91605431.cms

Yash Shukla, Rajan Rawal, S. M. (2014). India model for adaptive thermal comfort. Bureau Of Energy Efficiency, Government of India.